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Quantifying Steps During a Timed Up and Go Test Using a Wearable Sensor System: A Laboratory-Based Validation Study in Healthy Young and Older Volunteers

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Abstract—**Mobility is an important factor in maintaining health and independence in an aging population. Facilitating community-dwelling older adults to independently identify signs of functional decline could help reduce disability and frailty development. Step-count from a body-worn sensor system was compared with a criterion measure in healthy young (n = 10) and healthy older adults (n = 10) during a Timed Up and Go test under different conditions. Spearman's rank correlation coefficient indicated strong agreement between the sensor-obtained step-count and that of the criterion measure in both age groups, in all mobility tests. A body-worn sensor system can provide objective, quantitative measures of step-count over short distances in older adults. Future research will examine if step-count alone can be used to identify functional decline and risk of frailty.**

Clinical Relevance—**This demonstrates the correlation between step-count derived from a wearable sensor and a criterion measure over a short distance in older adults.**

I. INTRODUCTION

Mobility, defined as the ability to move or be moved freely in space is an important component of independence and in completing activities of daily living. The correlation between mobility, physical activity and health is well established [1]–[5] and maintaining independent mobility contributes to physical, psychological and social well-being in older adults [6]. A reduction or impairment of mobility is often an early sign of declining function and is recognised as a prognostic indicator for disability [7]. As a result of the natural aging process, older adults experience loss of muscle mass and strength with concurrent impairment in balance and mobility. This is associated with an increased risk of falls, development of frailty, hospitalisation and even death [8]. Frailty is a syndrome associated with ageing in which there is a reduction in physical and psychosocial function, the outcome of which is detrimental to independence [9], [10]. Early recognition of mobility impairment and appropriate intervention is important to facilitate healthy aging [11].

Mobility, specifically gait has traditionally been examined in laboratory or clinical settings through the use of force-plates, motion capture or instrumented treadmills, and in free-living environments through the use of self-reported activity diaries, questionnaires and standardised assessment tools. Both approaches to measuring mobility have inherent difficulties. Assessment of mobility in the clinical setting is costly, requires expertise and is suggested to represent capacity as opposed to an accurate reflection of habitual, everyday performance or behaviour [12], [13]. Self-reported methods rely on recall and are subject to potential reporting bias [14].

Advances in technology and the proliferation of unobtrusive body-worn sensors allow for the capture of more objective and quantitative measures of mobility in clinical and free-living environments. Body-worn sensors can be used to monitor aspects of mobility and physical activity and include pedometers to measure step-count, accelerometers, altimeters and global positioning systems (GPS) to measure speed, distance and postural transitions. These sensors can be incorporated into shoes and clothing, worn as pendants, attached for example to the wrist, ankle or trunk, or carried in a pocket.

Kinesis QTUG (Kinesis Health Technologies, Dublin, Ireland) is a wearable sensor and software system which provides a percentage risk of falls or frailty based on average values for gender and age. It has been validated for the assessment of mobility, prediction of falls risk and frailty estimate in older adults and those with disability or neurological impairments [15]–[17]. It does so through the quantitative measure and analysis of temporal-spatial parameters of gait during the standard Timed Up and Go (TUG) test. A TUG test is a validated activity test that measures in seconds, the time taken by a participant to stand up from a chair of standard seat height, walk a distance of 3m, turn, walk back to the chair and sit down. It is used to assess functional performance, balance and risk of falls in older adults [18].

Walking distance, speed and ability to climb stairs are common benchmarks of mobility. Accurately measuring step-count is an important factor in measuring walking distance and speed as has been demonstrated in previous research [19]. Research suggests that the accuracy of step-count is variable in older adults because of the characteristic changes in gait associated with ageing [20]. Gait-speed and distance over which step-count is measured are also important considerations [21], [22]. As a precursor to further study of parameters of mobility relative to frailty, the aim of this study is to examine if a wearable sensor system can accurately detect

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the number of steps taken over a short distance during various conditions of a TUG test in older adults and healthy young adults.

II. Methods

A. Participants

Participants were recruited through advertisements in a local golf club, tennis club and physiotherapy department. Those interested were assessed for eligibility and fully informed about the study. Inclusion criteria were 18 - 65 years of age, or > 65 years of age, healthy, independently mobile, physically capable of performing a series of mobility and physical activity tests, have no cognitive or neurological deficits and have no history in the past 12 months of orthopaedic trauma or surgery.

A convenience sample of twenty community-dwelling volunteers was recruited (n =10 > 65 years of age, and n = 10 aged 18 – 65 years). The study protocol received institutional ethics approval and all participants signed a written informed consent form prior to participation. Participants also fulfilled COVID-19-specific requirements.

B. Study Procedure

The study was carried out in two different sites for logistical reasons. All participants in the over-65 years of age group were assessed at site one while all those in the 18-65 years of age group were assessed at a separate site (site two). The set-up in both sites were comparable with the exception of the floor surface; a carpet-tile surface at site one and a wooden floor at site two.

Measurements of height, weight and leg-length were taken along with demographic details. Participants were instrumented with the Kinesis QTUG system with one sensor placed at each ankle as per manufacture's guidelines. Single-use elastic bandage was used to secure each sensor.

Participants performed a TUG test under three different conditions with a minimum of 1-minute rest between tests; at normal pace, at normal pace while counting in 3s backwards from 100 (TUG-cognitive), at normal pace while carrying a glass of water (TUG-manual). The chair used was without armrests, with a seat-height of 45cms. In the seated position, the participant's feet rested on the floor with toes positioned behind a floor-mark which indicated the start of the 3m distance. A second floor-mark at 3m distance indicated the turning point. The manual start-stop function of the Kinesis QTUG system was operated to coincide with the signal to start and with the finish of each TUG test and therefore used to manually time each TUG test.

C. Data Collection

Kinesis QTUG sensors were connected to a tablet (Samsung Galaxy Tab A 2016) via Bluetooth with data streamed in real-time and saved to the tablet in text form for offline analysis. The criterion measurement of steps taken was determined by a manual step count performed by the researcher in real-time with the 18-65 years of age group, while retrospective observation of video-recordings was used to obtain the criterion measurement of step-count in the > 65 years of age cohort.

D. Statistical Analysis

Data analysis was performed using Microsoft Excel-16 and SPSS-26 (IBM). Descriptive statistics of continuous variables are presented as Mean and Standard Deviation (SD). Data were tested for normality using the Shapiro-Wilk test. A *p* value of < .05 was considered statistically significant. Because of the small sample size, the relation between sensor-based step-count and criterion was analysed using Spearman's rank correlation coefficient. Bland-Altman plots demonstrate limits of agreement in each of the mobility tests for each age cohort. Each age cohort was analysed separately.

III. Results

Twenty participants were enrolled in the study, healthy older adults aged > 65 years (n = 10, age 68.7 ± 3.68, female n = 5) and healthy young adults aged 18 – 65 years (n = 10, age 47.7± 11.49, female n = 5). Video-recording on one male participant in the healthy older adult group was of poor quality and not deemed usable therefore data from nineteen participants were included in the analysis.

The results of the Shapiro Wilk test in each age group indicated normal distribution of variables. Results of the Spearman's rank correlation coefficient indicated there was a strong positive correlation between step-count measured by the Kinesis QTUG system and the criterion measure in each TUG test (Table I.). Bland-Altman plots demonstrating limits of agreement for each group and mobility test are presented in Fig. 1.

IV. Discussion

This study examined the correlation between a body-worn sensor system and a criterion measure of step-count obtained during three mobility tests over short distances in older adults and a healthy young adult group. Results suggest a strong relationship between the two methods in each group and each test. Spearman's correlation coefficient while significant in both groups is less so in the young adult group. This is in contrast with previous studies that suggest reduced accuracy with slower gait-speed [23], [24]. A possible explanation for

TABLE I. Comparing Step-Count from QTUG with Criterion

Group	Test	Manual step count Mean(SD)	QTUG step count Mean (SD)	Mean Absolute Error	r_s
Age 18-65 years	TUG	12 (1.15)	11.6 (1.17)	0.4	0.633*
	TUG-cognitive	13.40 (0.96)	12.5 (0.84)	0.9	0.776**
	TUG-manual	12.90 (1.37)	11.90 (1.19)	1.0	0.809**
Age >65 years	TUG	14.66 (2.12)	13.33 (2.34)	1.33	0.920***
	TUG-cognitive	14.66 (3.27)	14.33 (3.27)	0.33	0.824**
	TUG-manual	14.66 (1.93)	13.88 (2.57)	0.78	0.914***

Abbreviations: Spearman's rank correlation coefficient (r_s), Standard deviation (SD). **p*<.05; ***p*<.01; ****p*<.001

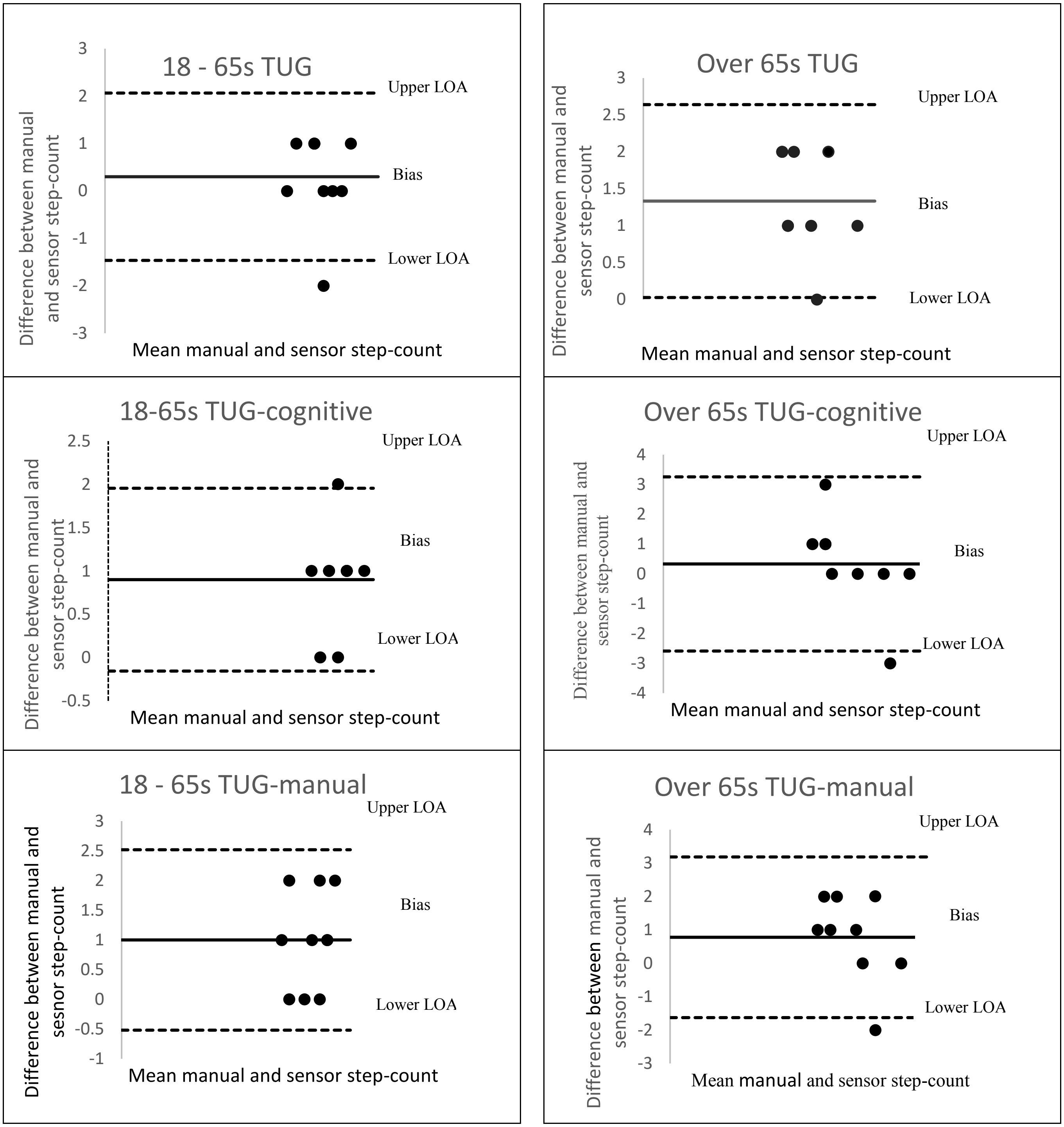

Figure 1. Bland-Altman Plot demonstrating level of agreement between manually counted and sensor-obtained step-count for each age group and each mobility test. Abbreviation: Limit of agreement (LOA).

this is the different methods of determining observed step-count adopted in the study. Manual recording of the mobility tests in the young adult cohort may have resulted in an error in step-count in this group. Mobility is a vital component of independence and contributes to physical, psychological and social well-being. This in turn reduces the risk of declining function, disability and frailty [7]. Walking accounts for the largest proportion of leisure and everyday activities and so it makes sense to measure it as part of an assessment of mobility [12], [25]. Accurately measuring step-count is an important first step in measuring mobility and physical activity [19].

Most assessment tools for identifying frailty or functional dependence incorporate a measurement of mobility [8], [26], [27]. As people age there is a tendency to move less. Having an objective method for older adults to measure their mobility and thus be alerted to any decline may facilitate early intervention and reduce the associated risks. This study is a first step in identifying the potential for a wearable sensor to record a simple parameter of mobility in older adults. Other studies have included step-count as one of a multitude of parameters to examine frailty [28], [29] but not, to the author's knowledge as a stand-alone parameter. Future studies will investigate if a simple, single parameter of mobility that can be used to identify levels of frailty can be independently obtained by community-dwelling older adults.

Limitations of the study include the small sample size, the risk of bias due to recruitment of volunteers and the inconsistencies between the two groups in determining step-count. While both methods are considered gold-standard, a video-recording would allow for the most rigorous method with at least two independent observers [30]. The risk of recruitment bias was mitigated by the wide-spread recruitment campaign and the inclusion criteria adopted.

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